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Production Strategies for Tight Gas Sands: A Case Study of the Upper Cozzette Blanket Sand

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ABSTRACT

The importance of the role that natural gas from tight formations would play in achieving energy self-sufficiency for the United States cannot be over-emphasized. One reliable source estimates the natural gas reserves of the tight sands of the Western United States alone to be more than 5700 trillion cubic feet. However, the technology for recovering this resource remains elusive, primarily due to lack of adequate understanding of the physics of fluid flow dynamics within this type of porous media. The fluid flow in tight formations does not subscribe to that normally associated with conventional reservoirs. It is believed that tight formations frequently possess dual porosity, and the flow field in these formations may be governed by more than one mechanism. The model utilized in this study possesses proven predictive capabilities, an essential ingredient to production forecasting, and hence is used as a framework for the development of optimal production strategies for the Upper Cozzette blanket sand. The model has multi-well capabilities and has options for either vertically or horizontally fractured wells and horizontal boreholes. Simulation results from a variety of production schemes are presented. The results provide some insight into production strategies involving horizontal boreholes and hydraulic fractures.

INTRODUCTION

Due to diminishing natural gas reserves and the need to establish energy self-sufficiency for the United States, low-permeability natural gas reservoirs, once deemed to be non-commercial, have begun to be recognized as a possible major source of future natural gas supplies. These reserves are substantial. For example, it is estimated that natural gas re of the Western United States alone is more than 5700 t cubic feet.[1] However, low-permeability gas reservoirs are "tight" formations and hence produce at low rates. Techn must be employed to enhance their productivity. These me include hydraulic fracturing or the drilling of hori boreholes.

References and illustrations at end of paper.

Hydraulic fracturing has been the most common m for enhancing the productivity of tight gas wells in the whereas the drilling of horizontal boreholes has just re been suggested as a viable completion option.[2,3,4,5,6] Signi reserve increases from low-permeability reservoirs also resulted from the practice of infill drilling.[5,7,8]

In this paper results from a number of numerical exe conducted to compare the recovery capabilities of v production strategies, are presented. These exercises inclu investigation of unstimulated vertical wells, vertically fra wells, and horizontal boreholes for several well spacings. Upper Cozzette blanket sand at the U.S. Department of En Multiwell Experiment (MWX) is the target of the fiel study in this analysis.

BRIEF DESCRIPTION OF THE NUMERICAL MODE

Gas transport in tight sands can be described by a mechanistic approach,[9] obtained by the superposition o flow fields, namely a concentration gradient field and a pr gradient field. While the first mechanism is a diffusion pr governed by Fick's law of diffusion, the latter is Darcian However, the transport of water within tight formatio strictly by Darcian flow. The gas and water transport equ are approximated by the finite-difference method, an resulting system of finite-difference equations is linearized by a generalized Newton-Raphson procedure. A detailed description of this model, as well as its attributes and capabilities, has been well documented in previous works.[10,11,12]

THE UPPER COZZETTE BLANKET SAND

The Upper Cozzette blanket sand is part of the U.S. Department of Energy's Multiwell Experiment (MWX) test site. This in-situ field laboratory, located near Rifle, Colorado, was designed to conduct in-depth geologic and engineering research into the characteristics of gas production from the tight formations of the Western United States. The multiwell facility consists of three wells (MWX-1, MWX-2, and MWX-3) that were drilled in a tight pattern (between 110 and 215 ft. at measured depth) through the Mesaverde formation in the Piceance Basin. Only two of the wells, MWX-1 and MWX-2, penetrate the Upper Cozzette. These two wells provided the means from which a large amount of technical data was obtained.

As a prerequisite for the development of production strategies applicable to tight gas sands, relevant data for the Upper Cozzette blanket sand must be obtained. These data of interest include porosity, permeability, initial reservoir pressure, initial water saturation, and formation thickness. The bulk of the data used in this investigation are the same as those established by Branagan et al.[13,14] However, it was found necessary to "tune" the model using permeability as the "tuning" parameter utilizing production and interference test data. As described in detail in an earlier paper,[15] the "tuning" exercises using the model described above resulted in an anisotropic permeability characterization of k_x/k_y = 0.125 md/0.01 md. The complete set of reservoir and well parameters used in the development of optimal production strategies for the Upper Cozzette blanket sand is contained in Table 1.

FIELD DEVELOPMENT STRATEGIES

Problem Specification

A series of simulations was conducted to investigate the effects of well spacing and well type for the purpose of arriving at optimal production strategies for the Upper Cozzette blanket sand. The problems simulated were designed to be representative of actual field practice.

Consideration was given to actual field practice regarding the modeling of horizontal boreholes and vertically fractured wells. It is a well-known fact that for a reservoir with an anisotropic permeability distribution, increased productivity for both horizontal boreholes and vertical fractures is achieved when they are oriented perpendicular to the direction of maximum permeability. This favorable situation is easily obtainable for horizontal boreholes, since reasonable level of control can be exercised over the direction of the borehole. However, with the vertical fracture, there is little contr
directional matters. In fact, the vertical fracture pro
somewhat parallel to the direction of maximum perm
Hence, the productivity increase, which could hav
obtained from the large surface area provided by the
fracture, becomes limited. Furthermore, in field pr
vertical fracture with infinite conductivity is not always p
Therefore, in order to achieve the most probabl
conditions, when modeling horizontal boreholes, the
oriented perpendicular to the direction of m
permeability. When modeling vertical fractures, the
placed both parallel and perpendicular to the direc
maximum permeability, thus establishing the range of
gas production. The vertical fractures were assigne
conductivity values.

Well Type and Spacing

A series of simulation runs was conducted to
insight into the effects of well type and spacing on gas r
Three well types (unstimulated, vertically fractur
horizontal) in conjunction with three spacings (80, 1
acres) were investigated. For the vertical fracture sim
two fracture lengths were examined (150 and 600 ft.),
the horizontal borehole runs, two borehole lengths (
1100 ft.) were considered. The results from this
simulation runs are summarized in Table 2.
comparisons are provided in Figures 1 through 7. In all
an abandonment flow rate of 100 MCF/day was used. O
this abandonment condition is arbitrary and will depe
the prevailing economics.

As expected, the smallest well spacing conside
acres) yielded the highest fractional recovery for every
considered. In all these runs, this well spacing also
abandonment the earliest. The results are summarized
2, which gives the expected recoveries at abandonment.
1 through 4 express the projected recoveries as a fun
both time and well spacing. Economics may dictate de
a field using a rather small well spacing, thereby ma
gas recovery in the shortest time possible. However, hig
densities implies higher drilling costs, and the curren
price of the gas must be able to support the chosen
program. On the other hand, if the current gas m
depressed, a viable field development strategy would b
larger well spacings to reduce drilling costs and pro
producing life of the reservoir.

Stimulated Vertical Wells

The results of simulation studies conducted to d
the impact of stimulation jobs done using vertical fra
vertical wells are summarized in Table 2, and Figures
Well spacings examined include 80-acres, 160-acres, a
acres. In all these runs, the abandonment condition spec
gas flow rate of 0.1 MMCFPD. For the unstimulated s
takes approximately 8 years to recover 502 MMCF
which is approximately 16% of the original gas-in-pla

3037 MMCF). The stimulated wells were designed with two fracture lengths, 150 and 600 ft., and two fracture orientations for a given fracture length. The first is the case in which the fracture is oriented parallel to the direction of maximum permeability, while the other case is that in which the fracture is perpendicular to the direction of maximum permeability. While the latter is more desirable in terms of productive capacity, the former is more probable in actual field practice as the fracture tends to propagate in the direction of least resistance. It should be noted that the purpose of studying both orientations is not to determine which would produce more, but rather establish a bound on the vertical fracture's productive capacity. In practice, it is not easily feasible to control the direction of fracture orientation.

As expected, the perpendicular orientation of the fracture (relative to the direction of maximum permeability) produces more than its parallel counterpart. (See Figures 2 and 3.) This disparity in realized production is slightly more pronounced for the 600-ft vertical fracture and is likely due to its larger surface area available to the formation (36,000 ft^2 versus 9,000 ft^2 for the 150-ft vertical fracture). The drainage effectiveness of the 600-ft fracture is greater than that of the 150-ft fracture and hence gives better recovery efficiency, both in terms of ultimate recovery and producing life. One observation that is worth mentioning is the fact that the time it takes to achieve essentially the same level of recovery is almost linear with well spacing for a given fracture length and orientation. The highest fractional recovery achieved was for the 80-acre spacing; however, the actual increase in fractional recovery with decreasing well spacing is quite marginal, from 0.223 for 320-acre spacing (G_i = 12,107 MMCF) to 0.251 for 80-acre spacing (G_i = 3037 MMCF). The real gain, however, is in the time required to obtain this recovery. Only 7 years is required for the 80-acre spacing as opposed to 28 years for the 320-acre spacing. Another interesting finding of this investigation is that the fractional recovery achieved with perpendicular orientation of the fracture is not dramatic (0.251 : 0.237 for the 600-ft fracture/80-acre system and 0.223 : 0.209 for the 600-ft fracture/320-acre system). The abandonment times for both cases are also comparable.

Horizontal Boreholes

As part of the development strategies for the Upper Cozzette blanket sand, horizontal boreholes, lengths 600 and 1100-ft, were also considered. Similar well spacings as for the vertical fractures were used. Again, the summary of the results are contained in Table 2. Detailed comparisons are provided by Figure 4. In all cases, the horizontal boreholes achieved substantially higher recoveries than unstimulated vertical wells. In the best case, as determined by fractional recoveries, the 600-ft and 1100-ft boreholes recovered 22.4% and 25.0% of the gas-in-place respectively, as compared to 16.5% for the unstimulated vertical well in an 80-acre system.

In comparison with stimulated vertical wells, it w appear from merely looking at the recovery numbers tha horizontal boreholes are out-performed by vertically frac wells. This is shown in Figures 5 through 7, which pr comparisons of each of the various production strategies t on a drainage area basis. However, such a comparison ca be made solely on the basis of length of the fractures horizontal boreholes since each present different area exposure to the formation. For instance, in the systems stu the area exposed by the 600-ft vertical fracture is about 3(square ft. (an idealized fracture spanning the entire thickne the formation), versus an exposed surface area of only square ft. for the 600-ft horizontal borehole. Clearly, factors must be given consideration, such as the abilit actually achieve the desired fracture properties. With the a of horizontal borehole technology, such concerns are minim

CONCLUSIONS

A fairly comprehensive study has been conducted v demonstrates the performances of various field develop strategies for the low-permeability Cozzette blanket sand. (the strategies studied, horizontal boreholes seem to be the effective means of recovering the most gas within the sh period of time. Vertical fractures aligned perpendicular t direction of maximum permeability perform at a comparable to the horizontal boreholes. In fact, for the 80 system, the 600-ft vertical fracture (aligned perpendicular t direction of maximum permeability) has almost ide production characteristics as the 1100-ft horizontal bore (See Figure 5.) The 600-ft fracture reaches abandonme about 6.3 years with a 0.251 recovery factor, whereas the ft horizontal borehole recovers 25.0% of the gas-in-pla approximately 6.2 years. It should be noted, however, tha favorable situation may not be easily obtainable in a practice since there is little directional control over fra propagation. Results also indicate that as well spacing incr vertical fractures appear to out-perform horizontal borel This is readily noticeable by comparing the prec performance of the 600-ft vertical fracture with that o 1100-ft horizontal borehole at larger well spacings. The si fractional recovery curves (for 80-acre spacing) be separated, with the 600-ft vertical fracture (aligned perpendi to the direction of maximum permeability) out-performin 1100-ft horizontal borehole. This phenomenon is most likel to the thickness of the formation being considered. Figu through 7 provide a succession of increasing well spa which illustrate this point.

Overall, the most optimistic fractional recovery ach within the constraints of the abandonment criterion impos approximately 25%, with an abandonment time of about 6 y This is the case of an 1100-ft horizontal borehole in 80 well spacing. The lowest fractional recovery is fo unstimulated vertical well in a 320 acre system, which yiel fractional recovery of 14.6% with an abandonment time of a 30 years. Furthermore, it is deduced from this study th vertical wells are to be the primary field development stra stimulation is essential in order to achieve reasonable recoveries within a realistic abandonment time. Another viable option is horizontal boreholes, which have been shown to be comparable to the "best-case" vertical fracture systems. Considering the idealization of the vertical fractures by assuming that they span the total formation thickness and are contained within the formation, horizontal boreholes appear to be the most favorable production strategy.

ACKNOWLEDGEMENT

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TABLE 1

Reservoir and Well Parameters for the Upper Cozzette Blanket Sand

Formation height, ft	30
Formation porosity, fraction	0.069
Formation water saturation, fraction	0.40
Reservoir temperature, °F	230
Gas viscosity, cp	0.018
Initial reservoir pressure, psia	6300
Critical water saturation, fraction	0.25
Critical gas saturation, fraction	0.0
Relative permeability to gas at S_{wc}, fraction	1.0
Relative permeability to water at S_{gc}, fraction	1.0
Vertical wellbore radius, in	3.5
Horizontal wellbore radius, in	6.0
Depth of formation, ft	7855
Relative permeability relationships:	Corey's Model
Permeability distribution (k_x/k_y), md/md	0.125/0.01

TABLE 2

Impact of Well Type and Spacing on Gas Recovery

Spacing (Acres)	Well Type	Total Recovery (MMCF)	Fractional Recovery	Abandonment Time* (Years)
80	Unstimulated	502	0.165	8.0
80	150-ft VF	610	0.201	7.9
80	150-ft VF**	651	0.214	7.7
80	600-ft VF	720	0.237	7.1
80	600-ft VF**	762	0.251	6.3
80	600-ft HB	679	0.224	7.2
80	1100-ft HB	758	0.250	6.2
160	Unstimulated	974	0.160	15.7
160	150-ft VF	1153	0.190	16.1
160	150-ft VF**	1225	0.202	15.7
160	600-ft VF	1389	0.228	14.6
160	600-ft VF**	1467	0.241	13.4
160	600-ft HB	1313	0.216	14.0
160	1100-ft HB	1400	0.230	13.2
320	Unstimulated	1774	0.146	30.4
320	150-ft VF	2120	0.174	32.6
320	150-ft VF**	2247	0.185	31.9
320	600-ft VF	2532	0.209	27.6
320	600-ft VF**	2694	0.223	25.8
320	600-ft HB	2237	0.185	23.1
320	1100-ft HB	225[illegible]	0.186	20.8

* The abandonment criterion is a flow rate of 100 MCF/day.
** Perpendicular to the direction of maximum permeability.

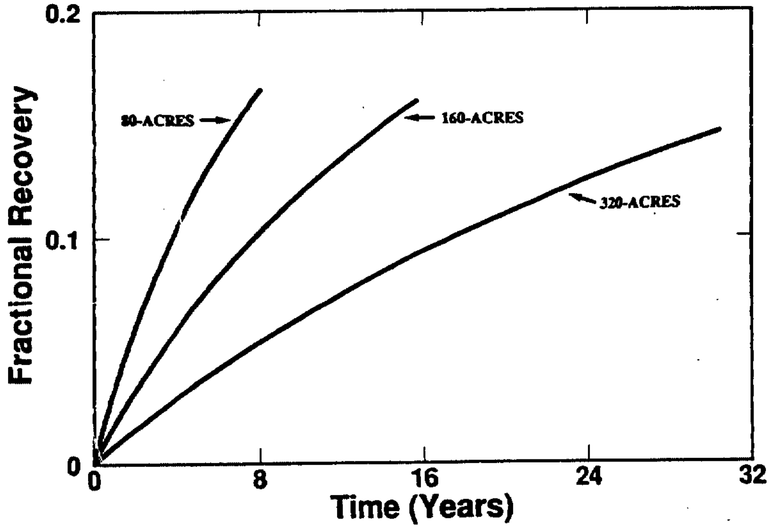

Fig.1 Impact of well spacing on gas recovery (unstimulated vertical wells).

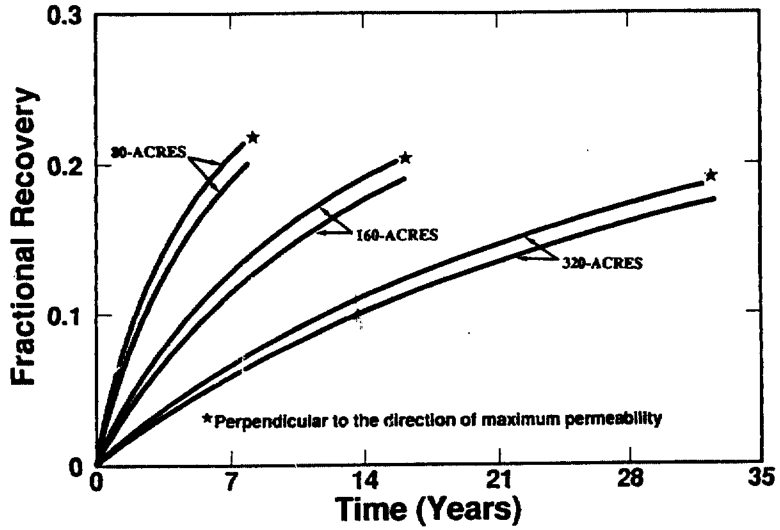

Fig. 2 Impact of well spacing and vertical fracture orientation on gas recovery (150-ft vertical fracture).

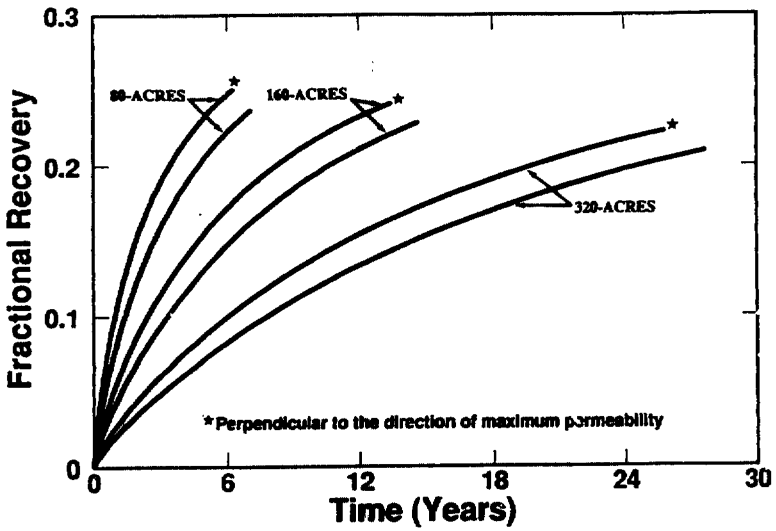

Fig. 3 Impact of well spacing and vertical fracture orientation on gas

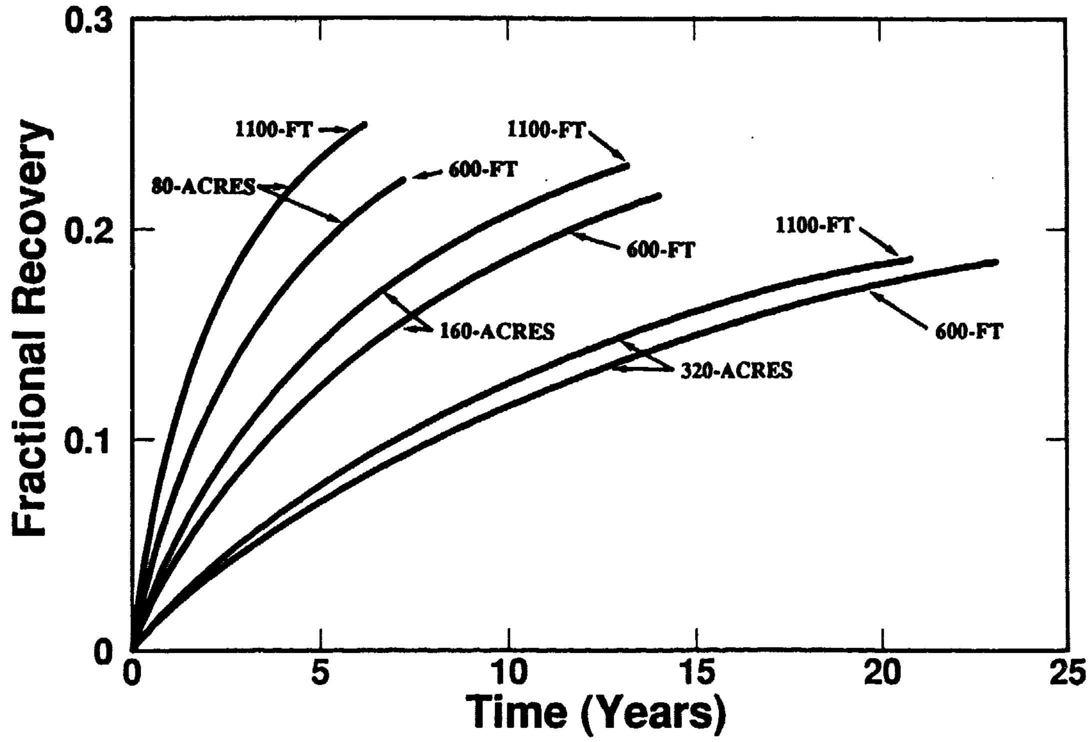

Fig. 4 Impact of well spacing on gas recovery (horizontal boreholes).
Note: Horizontal boreholes are perpendicular to the direction of maximum permeability.

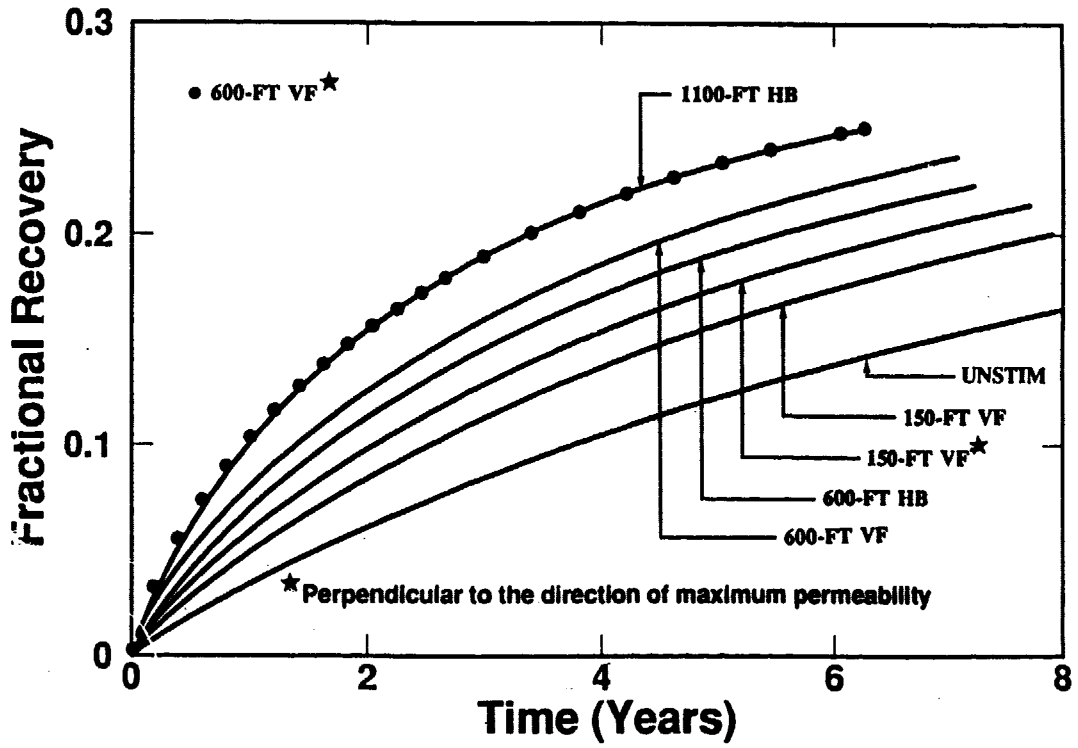

Fig. 5 Impact of well type on gas recovery (80-acre spacing).

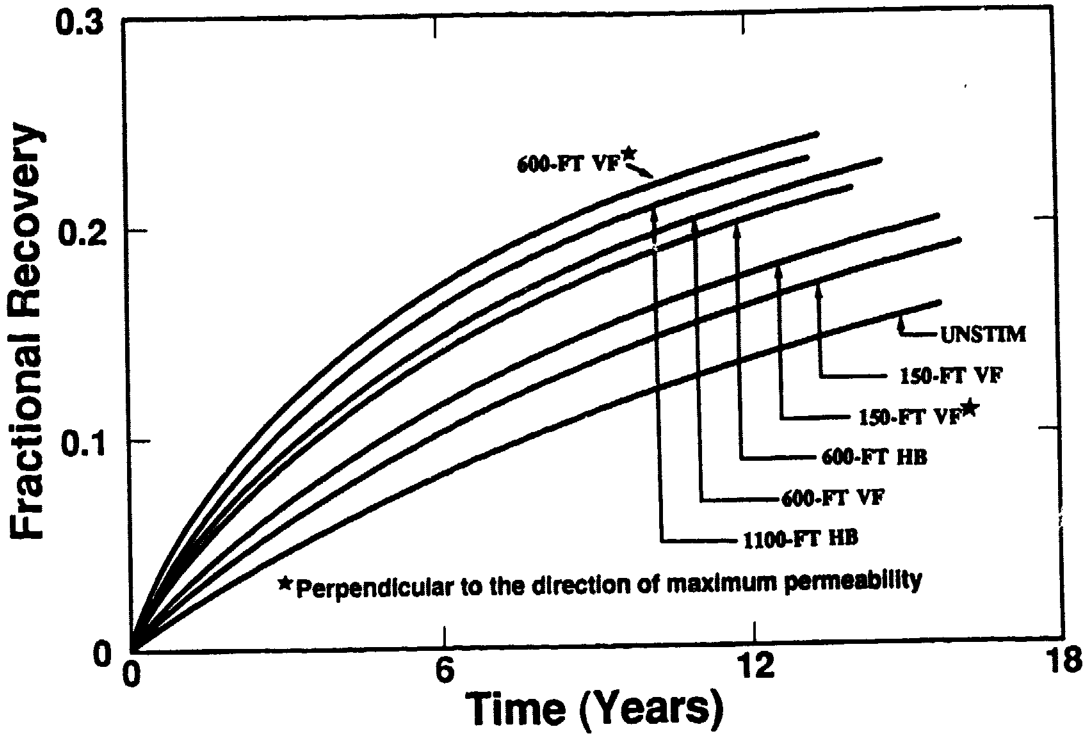

Fig. 6 Impact of well type on gas recovery (160-acre spacing).

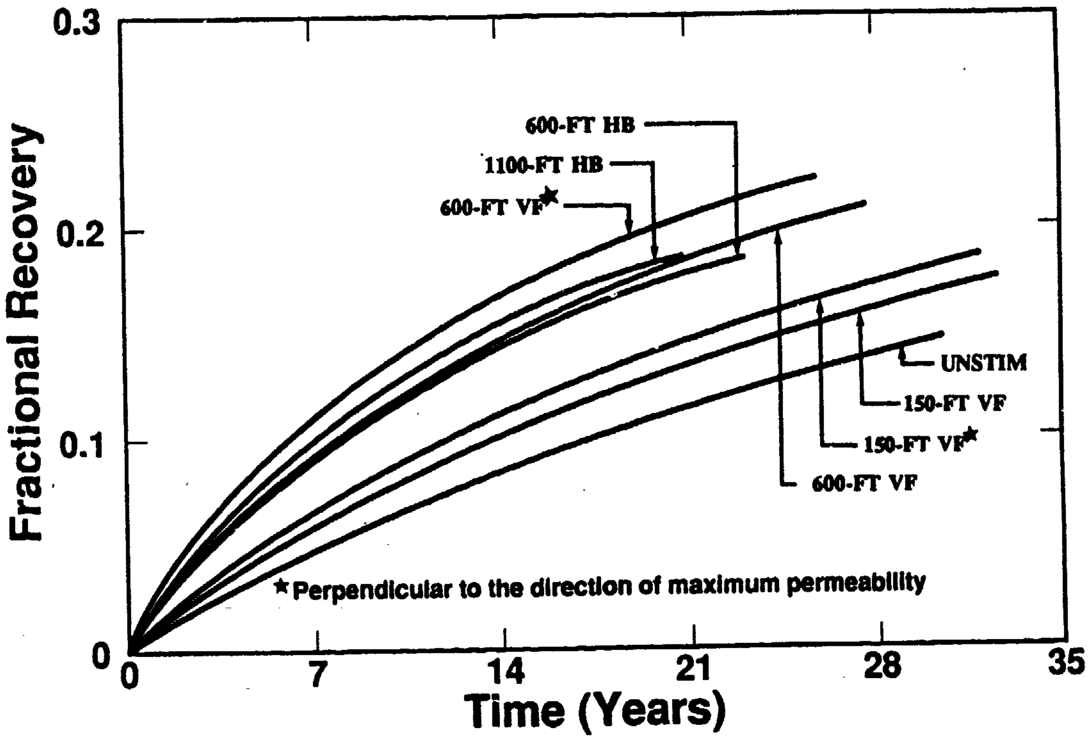

Fig. 7 Impact of well type on gas recovery (320-acre spacing).